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ABSTRACT

The Umka-Duboko is a large active landslide in the depth of 10-26 m, created in marly clays, taking up the area of 1.8 sq.km. According to the fact that the new road facility corridor located at the right bank of Sava river, on the meandering apex, crosses the landslide in the length of 3 km the characteristic remediation design solution is given. In this paper is observed seismic performance of this project. The analysis of potential liquefaction in motorway embankment and seismic stability of slope retained by embankment and hydraulic structure were made. The necessity was despite the limited seismic hazard data to give an assessment of potential maximal displacement of the slope and its rate of occurrence. The results obtained with used methodology are very good reference for a general design of this project and seismic performance assessment of landslides of this type.

INTRODUCTION

By both General and Preliminary designs of motorway from Belgrade to South Adriatic, i.e.E-763, at the exit from Belgrade, road facility corridor is located at the right bank of Sava river, on the meandering apex.

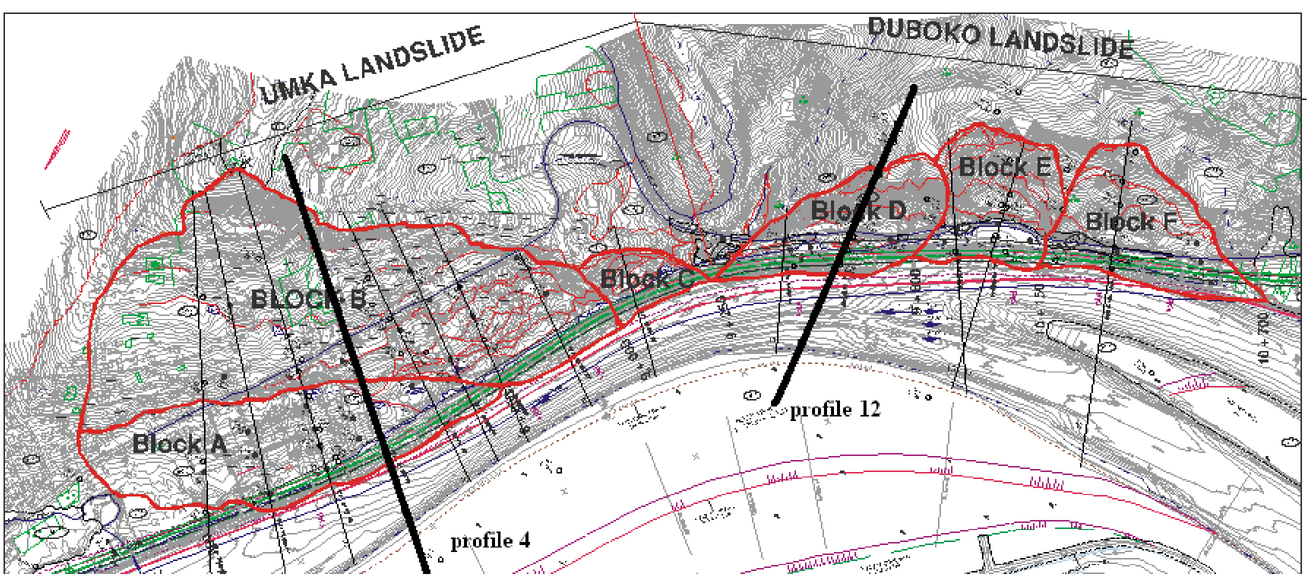


Figure 1. Umka-Duboko Landslide

The motorway crosses the landslide Umka-Duboko in the length of 3 km. It is the large active landslide with the depth of 10-26 m and dominant presence of marly clays, covering the area of 1.8 sq. km.

Based on analyses and a series of iterative procedures the decision has been made to:
-widen-up the river channel of Sava on the left bank;
-build a parallel protective-retaining and training structure made of crushed stone on the right bank;
-set the motorway road base on high embankment (made of dredged sand) behind the mentioned structure.

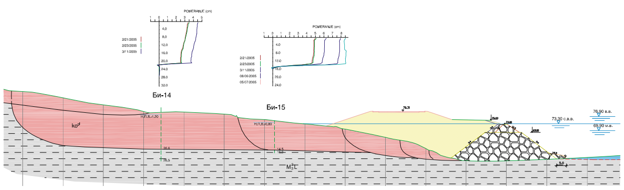


Figure 2. Engineering geologic profile 4 (block A)

It has also been envisioned to carry out the works of drainage, leveling and afforestation of unstable terrains.

In this paper the seismic performance aspects of this solution are studied. The analyses include the assessment of potential liquefaction in motorway embankment, and seismic stability of slope, retained by embankment and hydraulic structure.

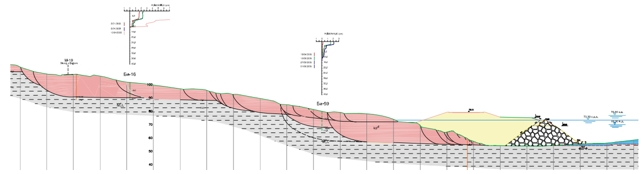


Figure 3 .Engineering geologic profile 5 (blocks A, B)

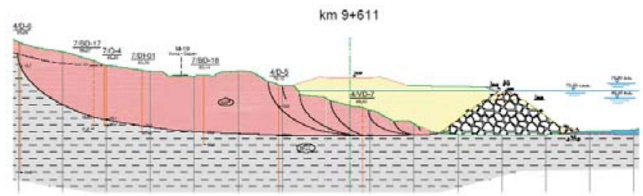


Figure 4. Engineering geologic profile 12. (block D)

GEOMECHANICAL INVESTIGATIONS

Investigation works

The results of previous investigations, with four investigation wells/shafts and 10 inclinometers were the basis for directing additional works, along the 15 profiles with 33 inclinometers.

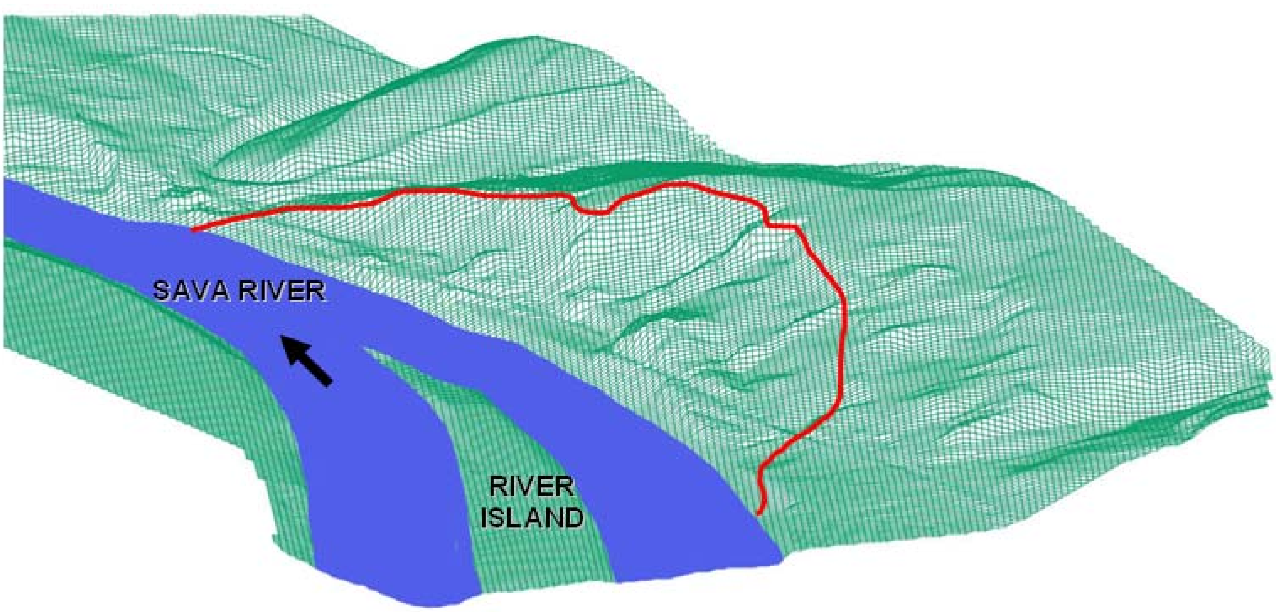
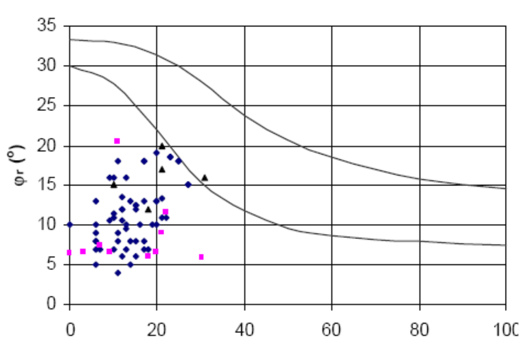


Figure 5. 3D model of slope Duboko.

In such a way the continuity has been obtained in checking up the landslide mechanism. These operations have been carried out by an expert team deeply involved in this issue for twenty five years. The extensive investigation works have been carried out in 2005, as follows:
-Detailed geologic plotting of terrain in the area of approximately 3 sq.km, with basic data at the scale of 1:1000;
-Aerial and field geodetic surveys of terrain, profiles, bench marks and location of works; Echo-sounding of the Sava river channel on the stretch of 5 km, along the 40. profiles; Exploratory boring and plotting of drill cores from 36 bore holes, depth up to 42 m, total 1190; Installation of inclinometers into 33 bore- holes, depth 12 - 42 m, total 770 m;
-Static penetrations (CPT) on three locations, depth up to 15 m, total 50 m;
-Laboratory testing of 140 samples of soil included: identification, classification, hardness, compression, compaction and load bearing capacity; Observations as regards the inclinometers, the Sava river level, ground waters in existing piezometers and wells/shafts with overall number of 180 measuring spots were carried out in the year 2005. Some 500 housing facilities and cottages were examined and the level of damages was also recorded. The survey of bench marks as of 1991 was also carried out;
The analyses of stability for established models of sliding were carried out along 15 profiles: under natural, repaired and earthquake conditions, together with the variations of levels pertaining to Sava River and ground water.

Geotehnical analysis and selection of design parameters

For established landslide models, along the 15. geotechnical profiles, natural stability of slope intercepted by the landslip has been analyzed in a recurrent mode, for design conditions of equilibrium Fs = 1 a tentative angle has been looked for, at average water level of the Sava river and maximum water-saturation on the slope. Laboratory residual resistance and tentative angles for design conditions of equilibrium are correlative. It has been recommended for the purpose of checking-up the effect of repair to utilize design residual parameters for Umka φr = 9°and cr = 0 kPa, while for Duboko φr = 11° and cr = 0kPa.



Fugure 6. Characteristic of landslide body

PROPETIES OF STABILITY ANALYSIS

The focus analysis was on the most critical profiles of each slope.(See Figure 1). In paper are presented the results of the most critical- slope Duboko.

Table 1.Critical profiles, results from previous analysis.

Profile	Stretch	Block(s)	φ_R	Fos	Slope
4-4	8+312	(A),B	9 º	1.42	Umka
12-12	9+611	D	11º	1.29	Duboko

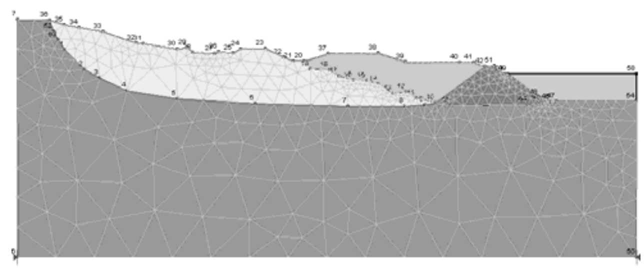


Figure 7."Duboko" slope model

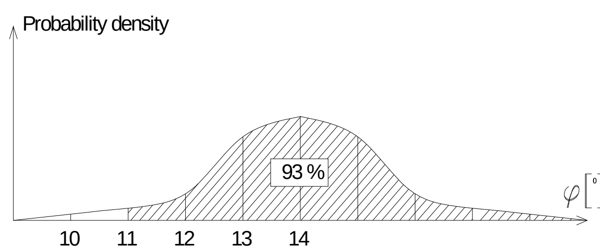


Figure 8. Assumed distribution of φr at slope Duboko

The numerous calculations were made for combining the different water levels and various values for φr, because the residual shear strength value suggested by geologic investigation of φr =11° is considered as too conservative and could not be mobilized along the whole slip surface. The normal distribution was adopted in that way that deterministic value covers around 93% of potential values of residual shear strength.

For the purpose of the analysis, according to mean value of φr=14° with the standard variation of 2° has been adopted.

According to the available data, and the project demands in this phase, equivalent linear model for soil behavior is used for the dynamic analysis. This type of soil modeling is in accordance with the relatively low level of earthquake magnitude that is expected in the observed area.

Stiffness of soils were obtained from the relation with SPT tests results, for natural soils. For hydraulic structure and embankment this parameters are given by preliminary project.

Having in mind the colluvium characteristics, lot of potential small slides are detected but they are not relevant from the viewpoint of the global seismic stability, so they are not considered in this study.

Seismic and flood flow input

On basis of the available seismic data from the seismic hazard maps, the location of Umka-Duboko is within the zone of maximum intensity of VIII according to MSK-scale. For better performance assessment the analysis is made with two characteristic earthquakes: (VIII MSK a_{max} =0.18g T=1000 years, VII MSK a_{max} =0.1g T=475 years).

Sava river flow regime is under the impact of backwater at the confluence with Danube River, more precisely with the operating regime of hydroelectric power plant "Djerdap". River levels, on the sector Belgrade - Obrenovac Township, are computed for three conditions at the confluence: backwater, depression and most probable coincidence of rivers Sava and Danube.

Design levels relevant for geotechnical analyses, design of repairs, reclamation and training works in the channel are as follows:

$Z_{1\%}$ = 76.90 mos - 100 years flood flow of Sava river,

Z_{mmf} = 73.30 mos- medium flood flow,

Z_{mwf} = 71.70 mos - medium water flow,

Z_{swf} = 69.90 mos - small water flow of Sava river.

RESULTS AND COMENTS

The factors of safety and Newmark's displacements in case of potential shaking are evaluated for different water levels of the river. The results for the mean values of shear strength and medium river flow are 1.371 and 58 cm for return period T=475 years.
Duration of the main phase of seismic tremor, in the range 6 to 8 seconds, indicate that the liquefaction may appear in some places, yet it does not essentially jeopardize the stability of parallel protective and training facility and road base.

According to the liquefaction potential assessment should be predicted high quality control of mechanical compaction of sand during execution and drainage system maintenance especially after heavy rainfalls.

Numerous of comparative analysis were made in order to determine infuence on each factor Just a few are presented here in table 2. and table 3. The results of "Umka" slope (figure 11) not presented in this paper showed the 20% better results.

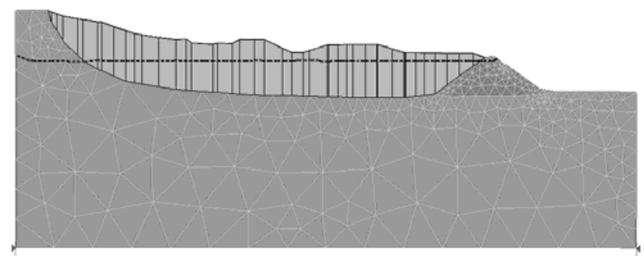


Figure 9."Duboko" slope stability $Zswf$ = 76.90 mos -100 years flood flow

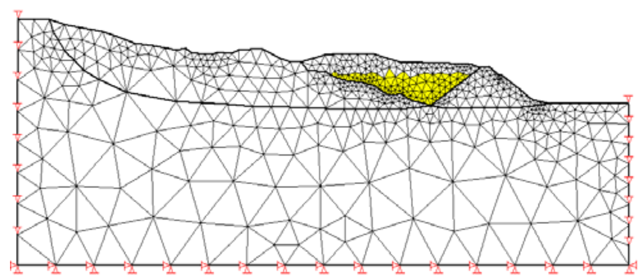


Figure 10."Duboko" Liquefaction zones. $Zswf$ = 69.90mos-small water flow of Sava river

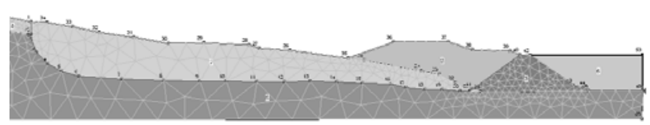


Figure 11. Umka Slope Model.

Table 2. Deterministic analysis: Static factor of safety and displacements during earthquake, T=475 years.

Z(meters over sea)	Factor of safety	Seismic disp.[cm]
76.90	1.251	79
73.30	1.319	65
71.70	1.371	58
69.90	1.428	51

Table 3. Static factor of safety and for different values of residual shear strength, T=475 years.

φr (°)	Factor of safety	Seismic disp.[cm]
10	1.257	76
11	1.371	58
12	1.487	46
13	1.603	36

The results using different residual shear strength for medium water level is presented in table 3. Considering the different water levels and values of residual shear strength the residual shear strength is pointed out as a main uncertainty parameter. The further factor of safety and displacement analysis is done with residual shear strength value as a only probabilistic parameter.

The probabilistic factor of safety analysis was conducted considering geotechnical uncertainty using Monte-carlo simulation. (figure 14)

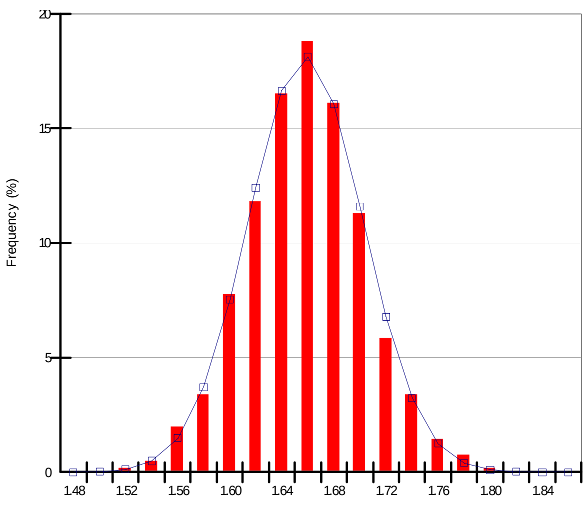


Figure 12. Factor of safety distribution

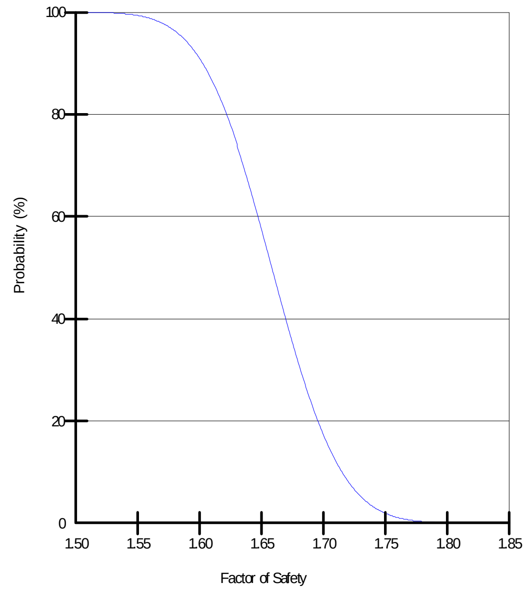


Figure 13. Factor of safety cumulative distribution

The results of probabilistic factor of safety analysis show that the stress state is not critical part of this analysis. There is 100% of safety that factor of safety is greater than 1.5. The care should be taken on the displacement performance of the slope.

Assesment of potential seismic displacement

It is assumed that earthquake displacement occurrences of certain value have Poisson distribution. The mean rate of occurrence of each displacement as maximal is obtained by using uncertainties of residual shear strength and maximal acceleration. The probability that obtained displacement is maximal, depend of probability that used shear strength value is minimal as well as that used $a_{\max}$ covers all possible accelerations in selected seismic zone.

$$p_{d \leq D_x}(\varphi_r, a) = p(\varphi_r \geq \varphi) \cdot p(a \leq a_{\max})$$

$$\lambda_{d_{\leq x} D} = \lambda_{earhhquake} \cdot p_{d<D}(\varphi_r, a)$$

The kind of back analysis is performed in order to evaluate probability of occurrence of each calculated displacement, considering two characteristic earthquakes:

P (zero d < D events in T years, from EQ1) =
1-P (there will be d>D events in T years form EQ1) =
1-P (failure if D is limit state, when there is no other d>D events from other EQs)

The probability of occurrence of each calculated displacement in certain time period is calculated by equation (1):

$$\text{Pf (T)} = 1\text{-exp}(-\nu_{d<D} \cdot T) \qquad (1)$$

The main assumption is that there are no similar displacements from two observed earthquakes, what can be confirmed on picture 14.

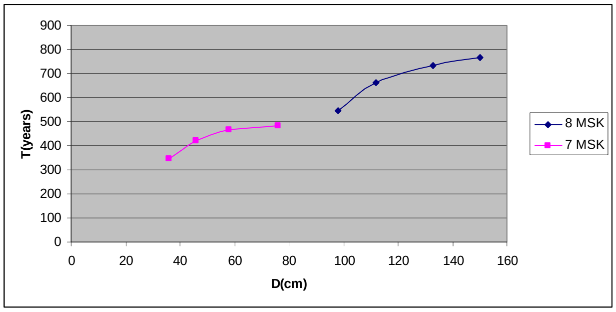


Figure 14. The evaluated rates of occurrences of Newmark's displacements of two observed earthquakes

The simplified methodology of evaluating this probability is used. The assumption was made that there is exponential relationship between limit state displacement value and probability of its occurrence in certain time period.

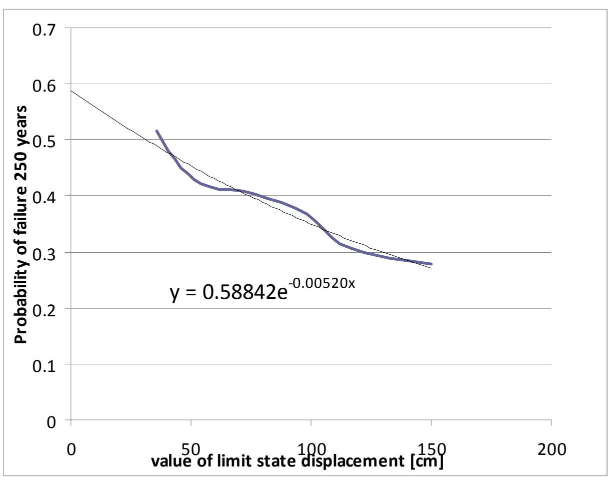


Figure 15. Probability of excidance in 250 years - Displacement.

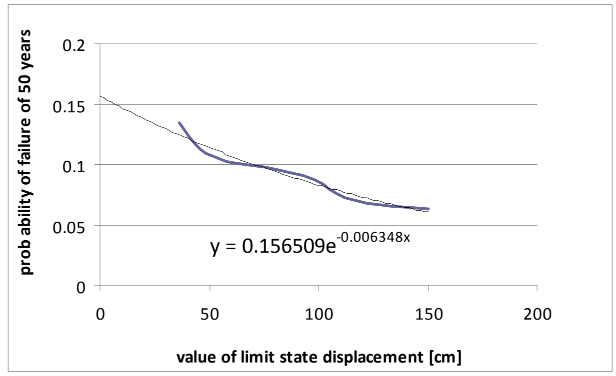


Figure 16. Probability of excidance in 50 years - Displacement

The detailed motorway design demands still has not be given, but according to codes for slopes ("the design should be performed using residual strengths and maintaining displacements < 15 cm, or using peak strengths with displacements < 5 cm") probability of failure was evaluated for limit state function g = d-10cm. The probabilities of failure are given for time periods of 50 and 250 years. The obtained probabilities of failure are: 0.14 and 0.57.(table 4).

Table 4. Results of analysis d_{limit_state}=10cm

Value of limit State displacement (cm)	Probability of failure in 50 years	Probability of failure in 250 years
10	0.14	0.57

By given solution erosion proces as a main landslide trigger factor is interupted, and the cotninous bigger movements are ceirtanly stoped the fact is the new motorway increase the demands for more percise performance assesment of the slope. Having in mind that the motorway is spreading along the slope (mainly perpendicular direction of sliding direction) bigger displacment at any crosssection can make the highway out of function.

As results have shown that seismic displacements of certain range surely can not be avoided, the suggestion for general project is to leave more space (funds) for emergency system and local road maintainence service.

The proposed procedure should be considered as usefull and very efficient method to identify key parameters which govern the limit state of deformation in geotehnical structures. Considering the limited seismic data and generaly low intesity of expected earthquakes no significant differences to detail releability analysis are expected. The main advantage of proposed analysis is its simplicity, and possibility for quick obtaining the results. There is no nessesity for reliability sowtware.

CONCLUSION

The results of the performed analysis give us the very good direction at this stage of project, and confirm that this type of solution for landslide mitigation has good seismic performance.

By given solution, erosion proces as a main landslide trigger factor is interupted, and the continous bigger movements are ceirtanly avoided during small to medium earthquakes.

The displacement assesment given as estimation of system behavior, contributes in the performance based preliminary design for this type of landslides.

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